T4 Chemical/Physical Treatment

This chapter describes chemical and physical treatment processes that can be added to the normal primary and secondary treatment process units. These chemical and physical treatment processes can aid, replace, or add to the removal of pollutants or adjustment of water chemistry in the wastewater stream.

Chemical selection and handling and types of applications are described in T4-1. The various filtration technologies, including granular media and fine screens, are addressed in T4-2.

T4-1 Chemical Treatment

Many chemicals in various forms can be applied in wastewater treatment to aid in sedimentation, nutrient removal, pH adjustment, odor control, disinfection, and sludge conditioning. Chemical treatment for enhanced sedimentation, nitrogen and phosphorous removal, and pH adjustment will be discussed in this section. Chemical treatment has increasingly limited applicability in wastewater treatment; water reclamation is being used more frequently than chemical treatment in the State of Washington.

T4-1.1 Chemical Selection and Handling

Chemicals added to the process work quickly and do not add time requirements. Some chemicals, however, are extremely dangerous and need special handling procedures and equipment.

This section focuses on the criteria, factors, and conditions that should be considered for the selection, storage, handling, and use of chemicals for the physical/chemical treatment of wastewater.

T4-1.1.1 Chemical Selection

Chemicals must be evaluated for each specific treatment process, and must be compatible with other liquids, solids, and air treatment processes. Chemicals shall have no detrimental effects on effluent quality, receiving waters, biosolids quality, or air quality. The impact of applicable local, state, and federal codes and regulations, such as the Uniform Fire Code (UFC), Resource Conservation and Recovery Act (RCRA), and OSHA, should also be considered when selecting chemicals for proper, safe storage and handling.

Laboratory tests such as jar tests or pilot-scale studies on actual process wastewater shall be used to select appropriate chemicals and dosage ranges. Operational data from wastewater facilities treating wastewater of similar characteristics may also be used to select appropriate chemicals and dosage ranges. Theoretical stoichiometric relationships should not be used for design as they tend to underestimate actual dosage requirements.

T4-1.1.2 Storage

Factors important to properly determine an adequate storage capacity are the reliability of the supply, quantity of shipment, the range of chemical use rates, and chemical decomposition during storage.

(1) Unless reliability of the supply and conditions indicate less storage is appropriate, storage should be provided to supply sufficient chemicals to satisfy the maximum 30-day demand period.

(2) Chemicals shall be stored in covered or unopened shipping containers, or be transferred into an approved covered storage vessel.

(3) Chemicals should be stored at locations that allow for efficient and safe handling. Storage locations and conditions should be compatible with the chemical type and form (dry, liquid, or gas), and should conform to all applicable local, state, and federal codes and regulations for the handling and storage of chemicals.

(4) Solution storage in day tanks feeding directly to a process should have sufficient capacity for 24-hour operation at the maximum design flow

or loading, and should conform to the design conditions of bulk storage tanks.

(5) Bags at dry chemical storage facilities should be stored in a cool, dry location that allows for easy, safe access and provides dust control. Bags should be stored above floor level to allow for effective cleanup. Dry bulk storage in tanks or bins should be designed with high and low level indicators and promote trouble-free, continuous feed (such as angle of repose, vibrators, and so on). Tanks and bins should be designed to produce the necessary environmental conditions (such as temperature and moisture). Dust control measures shall be incorporated into the design of dry chemical storage and handling facilities.

(6) Liquid chemical storage tanks:

- Should not be installed underground if possible.
- Shall have a liquid level indicator, an overflow, and an air vent.
- Shall be located within a containment area capable of holding a spill or overflow. The containment volume should be sufficient to hold the contents of the largest tank in the containment area, and should contain a leak-detection and alarm system.
- Shall have a high liquid level alarm for overflow protection if storing hazardous chemicals.
- Shall be designed to provide and maintain the necessary temperature to avoid crystallization or solidification of the chemical at available solution strengths. This is especially important for solutions of aluminum sulfate and sodium hydroxide.
- Storage tank vents should not be exhausted near heating/ventilating/air conditioning (HVAC) intake structures or into other tanks. For hazardous chemicals, vented air must be treated in accordance with the UFC. An additional pressure/vacuum relief valve may be installed on enclosed tanks to protect the tank from excessive pressure or vacuum.

(7) Ensure that adequate washing, flushing, and cleanout connections and equipment are provided in chemical storage areas.

T4-1.1.3 Handling

(1) The materials of storage tanks, pipelines, valves, gaskets, pumps and other appurtenances of chemical handling facilities must be compatible with the specific chemical(s) to be handled. Chemicals that are not compatible with each other, or the handling facilities, should not be fed, stored, or handled together.

(2) Provisions should be made for accurately measuring quantities of chemicals fed from bulk storage and day storage tanks over the range of design application rates. Transfer and feeding of bulk and diluted chemicals should be controlled by positive actuating devices.

(3) Storage, transfer, and handling facilities located in earthquake-prone regions should be designed to minimize the risk of spills and/or failures due to earthquakes.

(4) Design provisions should be made to control the release of dust during transfer, storage, and feeding of dry chemicals. Control shall be provided by use of pneumatic equipment or closed conveyor systems, facilities for emptying shipping containers into special enclosures, and exhaust fans and dust filters that put hoppers and bins under negative pressure.

(5) Acids and bases shall be:

- Kept in closed, chemically resistant shipping containers or transferred to appropriately designed storage facilities.
- Transferred in an undiluted state by gravity, air compressors, or pumps from the original container or vessel. Acids and bases shall not be hauled in open vessels.
- Transferred in such a manner as to minimize the risk of serious leaks or spills. Piping systems should be contained either through the use of double-walled pipe or placement of single-walled pipe in a containment trough or trench.

(6) The owners shall provide the necessary equipment and personal protection gear for the safe and efficient unloading and transfer of chemicals, such as carts, dollies, conveyors, and fork lifts. Facilities shall be designed to minimize the potential for slips, especially with polymers. See G2-7 for a more detailed discussion of safety considerations.

(7) Provisions shall be made for the storage, containment, and disposal of empty containers and drums to minimize exposures and comply with applicable codes and regulations.

T4-1.1.4 Housing

Structures, rooms, and spaces used to unload, transfer, store, or feed chemicals should be designed to provide a safe, effective working environment. It should provide convenient access for cleanup, equipment repairs and removal, and observation of operations and monitoring. These structures and spaces shall be designed and constructed in accordance with applicable local, state, and federal codes and regulations.

T4-1.2 Applications

Chemicals can be added to process units to further remove BOD, SS, and nutrients.

T4-1.2.1 Enhanced Sedimentation

Settling aids are used during primary clarification to enhance solids removal in the primary treatment process. Coagulants and flocculents increase the amount of solids a primary tank can remove, creating the opportunity for a smaller plant footprint and reduced construction costs.

A. Design Considerations

The best design for a clarifier is circular rather than a rectangular tank configuration. Rectangular tanks tend to have more currents, which can cause poor settling or short-circuiting. Existing clarifiers should be tested and proven in pilot studies. The center feed well should be a flocculating type (larger than the standard secondary feed well). This will allow for the slow mixing of the flocculent after injection. Clarifier inlets should be designed to distribute the wastewater equally at uniform velocities. Velocities should be low, generally 0.5 fps, to avoid the floc being sheered. Sludge volume in the tanks with chemical addition will generally increase by 80 percent. Consideration for the extra volume must be accounted for in pumping and digestion design. See T2-1.2 for a discussion of circular and rectangular settling tanks.

Coagulant must be added and mixed before the sedimentation process. The design for coagulant injection should include several injection points along the influent flow so that process personnel can find the injection point that gives the best results. Typically coagulants are injected into the line or channel flowing to a mixing chamber or the grit tanks, thus using them for mixing. The grit tanks used cannot have high velocities that can tear up the floc. Existing tanks will have to be tested for floc quality.

Flocculents (organic polymers) are added after the coagulant and can be added into the line feeding the clarifier or in the clarifier center well. Several injection points should be provided to give process personnel the opportunity to adjust polymer addition for optimum performance.

B. Operational Considerations

Feed pumps for the chemicals must be sized in keeping with the plant's intended range of flows. Coagulant doses do not proportionally follow flow as it increases but rather tend to taper off during high flows. A computer program that can be based on flow and input meters should control coagulant and flocculent dosage. Some coagulants will lower pH to the extent that the effluent will need adjusting. Plants with low influent alkalinity (less than 100) will be more susceptible to pH problems.

Chemical sludge will pump more easily than primary sludge. Sludge density will be between 4 and 7 percent. Sludge compaction will depend on the size of floc. Smaller floc will compact more and settle faster. Some chemical sludge with low pH will take longer to digest as it inhibits the digestion process. The volume of the digester should be increased to accommodate this. Chemicals containing sulfur will also generate more hydrogen sulfate in the digester gas. Design all gas piping to account for this more aggressive chemical.

C. Reliability Criteria

All chemical feed equipment must have a backup system. Some chemicals are very aggressive (high or low pH) so all equipment and the room housing the equipment should be designed for its pH. Polymers are extremely slippery when wet. The design should isolate this area by use of containment walls or elevated walkways, which can be easily cleaned by hosing them down. See G2-7 for a more thorough discussion of safety considerations.

Sludge lines should be glass lined and capable of back flushing with the opposite pump. A process water line attached to the sludge line is also desirable in case the sludge gets too thick, or to clean the line during shutdown.

Clarifiers should have one backup drive unit on hand for reliability.

T4-1.2.2 Nitrogen Removal

Several chemical/physical processes have been used for nitrogen removal. Although biological treatment is often the most attractive nitrogen control technology, physical and chemical processes are technically feasible. The three major processes include:

- Breakpoint chlorination.
- Selective ion exchange.
- Air stripping.

Although these processes are technically feasible ways of removing nitrogen, Ecology does not anticipate widespread use of any of these processes for nitrogen removal in the State of Washington because of high costs and environmental concerns about the use of chemicals.

T4-1.2.3 Phosphorous Removal

Chemical phosphorus removal from wastewater involves the addition of metal salts (aluminum or iron) or lime to wastewater to form insoluble phosphate precipitates, removal of the precipitate from the wastewater, and disposal of the precipitate with the settled sludge. Many process options are available, but the decision made by the designer involves:

- Selecting the chemical to insolubilize the phosphorus and estimating dosage requirements.
- Selecting the point of chemical addition.

Although these processes are technically feasible methods of removing phosphorous, Ecology does not anticipate widespread use of chemicals for phosphorous removal in the State of Washington because of high costs and environmental concerns about the use of chemicals.

T4-1.2.4 pH Adjustment

One of the most common types of chemical processes used in wastewater treatment is pH adjustment. pH adjustment simply raises or lowers pH to a desired value. Removing excess acidity or alkalinity by chemical addition to provide a final pH approximately equal to 7.0 is called neutralization. The volume, kind, and quantity of acid or alkali to be neutralized or partially removed are variables influencing the selection of a chemical agent.

Many methods may be used to neutralize or adjust acidic (low pH) wastewater. These methods include:

- Mixing separate acidic and alkaline waste streams so that the net mixture has a nearly neutral pH.
- Passing acid wastewater through beds of limestone (if the waste stream does not contain metal salts, sulfuric, or hydrofluoric acids that coat the limestone).
- Mixing acid wastes with lime slurries or dolomitic lime slurries.
- Adding the proper amounts of concentrated caustic soda (NaOH) or soda ash (Na_2CO_3) to acid wastewater.

Mixing acid and alkaline wastes is generally not possible in municipal facilities, and the use of limestone beds requires bed replacement—a major drawback. Therefore, only the third and fourth methods are used in municipal wastewater treatment and discussed here.

T4-2 Physical Treatment

Physical treatment, in contrast to chemical or biological treatment, is based on the concept of forcing the process stream through a porous media causing a physical separation of solids from the liquid. See Chapter T2 for additional information on sedimentation.

T4-2.1 General

This section describes the general considerations for using filtration technologies for liquid stream wastewater treatment, including granular media and fine screens (micro screens). Although the most common application of filtration is for advanced wastewater treatment SS removal (algae and biological floc), filters can also be used for removal of BOD, nutrients, metals, inorganic ions, and complex synthetic organic compounds. Filtration can also be used in the primary or secondary treatment processes for removal of particulate BOD. The designer should evaluate the possibility of filtration systems to achieve more than one principal removal function or to augment or replace other treatment process units.

Filtration is normally associated with advanced wastewater treatment so that the treated effluent can be reused beneficially or disposed of properly. See Chapter E1 for filtration related to water reclamation and reuse.

Where chemicals are to be used to facilitate the filtration process, see T4-1.

If filtration is to be utilized for particulate BOD or nutrient removal within the primary or secondary phases of wastewater treatment processes, see also Chapter T3.

Filtration backwash contains removed solids, chemical flocculents, and coagulants and needs to be handled accordingly. See Chapter S.

New types of filtration equipment continuously become available and are capable of meeting a variety of treatment goals. These general guidelines should be used with good engineering practice for most applications. Appropriate planning and judgment must be used in selecting and designing filtration systems to meet the needs of specific projects. These general guidelines should be used with sound engineering for most applications.

T4-2.2 Applications

In order to assess the possibility of using a filter system, the designer should carefully evaluate the treatment goals, characteristics of the waste stream, and the potential filtration technologies. In many cases, several filter technologies may perform adequately and final selection may be based on cost, O&M requirements, or site space limitations.

T4-2.2.1 Solids Removal

- **Lagoon effluent filtration for enhanced solids removal.** Filtration is generally applied to meet more stringent effluent solids limits than can be achieved in the lagoon treatment system. Lagoon effluent filtration generally requires the addition of a coagulant (alum, ferric chloride, ferrous sulfate, etc.) and a coagulant aid (polymer).

- **Filtration for enhanced solids removal following secondary treatment prior to discharge.** This is generally applied when effluent requirements are more stringent than secondary treatment can achieve.
- **Filtration for in-plant nonpotable water reuse.**

T4-2.2.2 Nutrient/Metals Removal

Filtration can be used to remove chemically precipitated phosphorus and, in rare instances, chemically precipitated metals.

In the application of filters for phosphorus removal, phosphorus is generally precipitated in the wastewater by adding a coagulant and coagulant aid upstream of the filtration process. The most common coagulants are alum, lime, sodium aluminate, ferric chloride, and ferrous sulfate. Other specialized chemicals and coagulants have also been developed for phosphorus precipitation. Polymer is generally the coagulant aid of choice.

The coagulants and coagulant aids can be added in upstream processes (primary clarifiers, secondary clarifiers, tertiary clarifiers, and tertiary flocculation basins) or directly upstream of some filters that can provide in-bed flocculation and direct filtration.

The filters remove precipitated and coagulated phosphorus-bearing solids which carry over from the upstream processes or which are formed in flocculation basins or in front of the filters themselves.

Metals such as copper, nickel, chromium, and lead can also be precipitated ahead of filters and removed in the filters. This is quite rare in municipal wastewater treatment plants; however, it may be appropriate where industrial wastewater is treated separately from municipal wastewater.

Metal removal typically requires adjusting the wastewater's pH up to the minimum solubility point for the metal of concern. At the minimum solubility point a metal hydroxide precipitate is formed (such as $Cu(OH)_2$). The metal hydroxide precipitate is then normally filtered following sedimentation.

The pH of the wastewater is normally adjusted by the addition of lime or sodium hydroxide (caustic).

T4-2.2.3 BOD Removal

BOD removal can also be enhanced through filtration. The applications for BOD removal are similar to those for solids removal. However, it is important to emphasize that only nonsoluble, and in some cases colloidal, BOD can be removed. Truly soluble BOD cannot be removed by filtration.

The applications for BOD removal by filtration include:

- Primary effluent filtration. (See T4-2.2.1.)
- Tertiary BOD removal following secondary treatment for enhanced removal of colloidal and nonsoluble BOD. (See T4-2.2.1.)
- Lagoon effluent filtration. (See T4-2.2.1.)

T4-2.2.4 Reclamation/Reuse

Applications for filtration in reclamation and reuse of wastewater are widespread. Filtration of wastewater for reclamation and reuse is applied to minimize virus and pathogen carryover to the disinfection process. Filtration in this application has been studied extensively and it has been determined that turbidity is a good indicator of filtration effectiveness. Effluent turbidity of 2 Ntu or less can be achieved through the careful application and operation of filters on secondary effluent. When filtration is required for reclamation or reuse of wastewater, the addition of coagulants and coagulant aids is required.

See Chapter E1 for a thorough discussion of reclamation and reuse.

T4-2.3 Media Considerations

The following discussions outline the main design issues to be considered.

T4-2.3.1 Separation of Solids from Water

The fundamental purpose of filtration media (granular and fine screens) is to separate solids from the liquid stream flow and also to be cleaned (backwashed) efficiently. Selecting the proper filtration media with reliable backwash abilities is the most important step in the design of a filter. Often several possible filter types may be suitable for a given filtration application. A thorough evaluation of the specific project constraints and cost comparisons may help to determine the best filter system choice. The engineer’s role in determining the filter media will be governed largely by whether a manufactured package unit or a specially engineered (custom) filter plant design is selected.

T4-2.3.2 Filter Media

A wide variety of media is used for filters, as follows:

- **Granular media**. Sand, anthracite, granular activated carbon, garnet, ilmenite, gravel. These media are usually chosen for their particular grain size and specific density and are contained in a vessel or tank that creates a bed depth ranging from 11 to 72 inches. Monomedia is the use of one kind, density, and size of granular media. Dual or multimedia is the use of two or more kinds, densities, and sizes of granular media.
- **Microscreens**. Metal screens, wire cloth, metal fiber, natural fiber or fabric, synthetic fiber or fabric, paper, plastic, fiberglass. These media are chosen for their specific opening size and are two-dimensional (flat surfaces).
- **Other**. Diatomaceous earth, synthetic (fuzzy balls), resin beads (charged and uncharged).

Selecting the appropriate media (and filter type) depends on the treatment objectives and consideration of the other factors presented in this section.

T4-2.3.3 Characterizing Solids and Feed Water

The solids contained in wastewater and wastewater effluents typically have widely varying physical characteristics and concentrations. The filter media must be capable of functioning efficiently and reliably at all anticipated loading rates and for all different types of solids that need to be removed. Solids typically include biological floc, algae, chemical floc, and untreated wastewater solids. Usually upstream processes (primary and/or secondary treatment) provide feed water to the filter. The engineer should carefully evaluate and have a good understanding of the performance and reliability of those upstream processes when selecting the filter type and media.

The design engineer should define the water and solids characteristics for the entire range of possible feed water conditions. Seasonal changes in water temperature, solid loadings, and water chemistry (pH, alkalinity, hardness, conductivity, etc.) can have a significant affect on filter performance. Solids characteristics such as floc size and strength may also change seasonally and should be defined during design. It is recommended that the water and solids characteristics (rate, concentration, composition, etc.) of the flow stream be defined on a monthly basis (or as otherwise necessary) and that possible peak loading conditions be identified.

Other feed water characteristics that may be detrimental to specific filter media should also be identified. Chemicals, inorganic precipitates, or particles (for example ozone, calcium carbonate, or clay, respectively) may damage or clog certain media and should be identified and considered in media selection. Industrial wastewater may have specific characteristics (such as chemical reactions with filter aids) that pose problems for filtration systems.

T4-2.3.4 Filtration Mechanisms

After defining the full range of filter feed water characteristics as outlined above, the filtration mechanism(s) that would be suitable for a specific filter application can be identified. Filter media (granular and microscreens) may remove solids from the liquid stream by one or more of the following:

- **Straining.** Based on the mechanical and chance contact of the media with the solids and that the solid (particle or floc) size is larger than openings in the media. Particles smaller than the pore size may also be strained if multiple particles bridge the pore opening. This is the principal mechanism for microscreen (surface) filtration.
- **Nonstraining.** Based on other forces that act upon the solid particles; includes interception, adhesion, attachment, adsorption, electrostatic, sedimentation, and flocculation. These mechanisms are predominantly in granular media filters.

T4-2.3.5 Solids Capture

Utilizing one or more of the solids removal mechanisms described above, filtration media will accumulate the solid particles either on a surface layer (microscreens or slow sand filters) or within the depth of the bed (conventional or rapid sand filters). Some filters (such as a pulsed bed) may actually use both methods of solids capture. Most filters have a limitation for the rate at which solids can be applied. That rate may be expressed in terms of TSS (mg/l), turbidity (Ntu), BOD-particulate (mg/l), or other constituent concentration. The filter media will also have a maximum capacity for holding a given volume (or mass) of solids.

The design engineer should utilize the information known about the feed water solids characteristics and loading rates in determining if the appropriate filter media may utilize surface straining or deep bed solids capture or both (such as a pulsed bed). Proper assessment of this factor is important in order to have reasonable backwash operations. Misapplication of this factor would likely result in excessive backwash frequency, excessive backwash water use, reduced plant capacity, and high operating costs. Usually historical data, pilot tests, or manufacturer’s recommendations can confirm which type of filter media would be appropriate.

T4-2.3.6 Backwashing

A filter can function efficiently only if the backwashing system cleans the media thoroughly and takes full advantage of the solids storage capacity. A properly designed and operated filter should reach the backwash stage when the captured solids just begin to emerge in the effluent and simultaneously an upper limit of head loss across the media is reached. There are many methodologies and kinds of equipment for controlling and backwashing filter media, and they are typically designed to be compatible with the particular media type and solids storage location.

Backwash methods are generally divided into two categories: batch and continuous.

Batch backwashing of a granular media filter requires a filter cell (either a discrete portion or a unit of several in service) be removed from duty, stopping the feed water flow, initiating a washwater stream (with or without air agitation) to expand the granular media bed, dislodging the solids from the media, carrying them away, and then restoring the filter cell back to service. The design engineer must oversize the filter design capacity to account for this backwash operation (at least one cell or unit is always offline for backwashing). Some surface media (microscreens) may also have similar batch backwash methods. Batch backwashed filters generally depend on control and instrumentation systems that monitor solids breakthrough and terminal head loss.

Continuous backwashing systems for granular media filters utilize mechanisms that constantly remove a small portion of the dirty media, process it through a cleaning device, carry away the solids, and return the clean media to the filter bed. Because the feed water flow is not interrupted and backwashing is occurring constantly, there is no need to “oversize” the total filter design capacity. Continuous backwashed filters typically do not have solids breakthrough or terminal head loss. Most surface media (microscreens) use a continuous backwash method.

The design engineer should consider the following factors when selecting a filter system:

- **Appurtenant support equipment**. Support system components needed for bed expansion, surface washing, and/or air scour systems typically include water pumps, air compressors, and tanks. Space for such equipment with related piping and controls may occupy a significant amount of site area and usually requires a building for protection from weather. Equipment capacity and standby units must be selected for proper backwashing performance.
- **Automated equipment and controls**. Motor-operated valves, solenoids, traveling bridge motors, and drives and other electro-

mechanical devices must be reliable and located for easy inspection and service.

- **In-bed piping and nozzles**. All piping and nozzles associated with surface washing or subsurface agitation devices should be made of corrosion-resistant materials and securely mounted. It is difficult to inspect and repair such items once they are placed into service.
- **Water quality monitoring**. Turbidimeters should be located for reliable operation, easy inspection, and cleaning. This is especially important if they are part of an automatic control function used to pace chemical feed rates, or automatically trigger backwash cycles, alarms, or system shutdowns.
- **Flow meters**. Flow meters should be included on the backwash system to measure backwash water and air scour flow rates. Flow meters should be selected for reliable operation and located for easy inspection and service.

T4-2.4 Granular Media Filters

Granular media (sand, anthracite, gravel, etc.) generally offers the greatest potential for reliably and efficiently meeting solids removal needs because it offers the following:

- A wide variety of media sizes and densities to choose from; and
- The varieties may be used individually (monomedia), mixed, or arranged in specially layered combinations (multimedia).

T4-2.4.1 Gravity Filters

A. General

Gravity filters are open to atmospheric pressure and rely only on hydrostatic pressure (due to feed water depth) to produce the driving force to move the water through the media. The optimum design should seek to achieve an economic combination of filter size, head loss, and run length.

- The direction of flow through the media may be up, down, or radial.
- Backwash methods can be batch or continuous.
- Gravity granular media filters are normally used for large installations.
- The granular media may be mono-, dual- or multimedia.
- Terminal head loss is usually limited to 8 or 9 feet and may be much less for automatic backwash filters.

B. Coordination with Plant Hydraulic Profile

- A gravity filter must be carefully integrated with the hydraulic profile of the total plant to avoid interference with other upstream and downstream process units.
- It is recommended that filtrate bypass channels or piping (with valves as necessary) be provided in order to waste or recirculate inferior filtrate during initial startup, upsets, or other unusual operating periods.

- Feed water for the gravity filters is usually pumped from the preceding process unit. Variable speed pumps can provide the necessary flexibility to coordinate with variations in other plant flow rates.

C. Production Rate and Head Loss Considerations

- Rate of flow through gravity filters can be variable or continuous.
- Gravity granular media filters typically require from 12 to 48 inches of hydraulic head to produce the driving force necessary for economic operation. Some filters may operate with more head, perhaps up to 10 feet, depending on the control scheme, type of solids, and specific media characteristics.
- Flow equalization should be considered to minimize the adverse impacts of peak flows on filter hydraulics.
- Most microscreen filters use gravity for the feed water driving force.
- Production (loading) rate is generally defined as the flow rate over the bed surface area: gpm/sf. Normally this ranges from 2 to 5 gpm/sf, however higher loading rates are possible (up to 10 or 12 gpm/sf) given sufficient study to verify proper performance.
- Filters are often assessed in terms of their production efficiency or effective filtration rate. In simplified terms, this is the ratio of the volume of filtered water divided by the volume of backwash water for a given run period or through a unit area of filter. If the time to breakthrough and the time to terminal head loss are maximized, and occur simultaneously, the filter would achieve maximum production efficiency.
- Manufacturers of filter equipment usually have good knowledge about the general capabilities of their equipment and have attempted to provide systems that are efficient. However every process stream is different and the designer must conduct pilot tests to establish pretreatment needs, chemical application considerations, and to know if the filter performance can be optimized at the full range of expected loading situations.

D. Backwashing

- The method of backwashing must be appropriate for the media.
- Backwash methods should attempt to minimize the amount of washwater used.
- Air scour or air agitation should be used for wastewater effluent filters.
- Surface washers may be necessary with certain media and filter types.

E. Control Considerations

There are two basic types of filter control schemes that vary primarily in the manner in which the flow and driving force (influent head) is applied across the media:

(1) Constant rate filtration uses a flow meter and modulating valve or flow control valve to maintain a constant flow rate to any given filter. This results in a variable water level above the filter media which rises as the filter begins to retain solids. When a filter reaches a maximum influent head, the backwash cycle is initiated. Disadvantages of constant rate filtration are (1) higher capital costs due to needed structural configurations between the influent and effluent, and (2) higher maintenance costs due to complexity of the flow rate control devices.

(2) Variable declining rate filtration uses a common influent header or channel, operating at nearly constant head to all filters so that the cleaner filters receive more flow than the dirtier filters. The advantages of this system are that the head needed for operation is less and the adverse effects of removing a unit for backwashing are minimal. Each filter has a flow restricting device (usually an orifice plate) on the effluent conduit to limit maximum flow. The designer is cautioned that this type of operation could conceivably result in an event in which all filters need to backwash simultaneously. Controls should be provided to preclude this.

In addition, manufacturers of filter equipment have developed some similar variations on the above control systems that provide improved performance, flexibility, and reliability.

T4-2.4.2 Pressure Filtration

A. General

Pressure filters utilize enclosed vessels that contain the filter media and force feed water through the media with pumps. The direction of flow through the media bed may be up, down, or radial. Backwash methods can be batch or continuous. Pressure filters are normally used for small installations, have higher energy requirements, and are mechanically somewhat complex.

B. Coordination with Plant Hydraulic Profile

Because pressure filters utilize enclosed vessels and pumps, the systems offer great flexibility within a plant hydraulic profile and can be placed at virtually any convenient location or elevation. The designer may be able to take advantage of the filtrate residual pressure to convey it to remote clearwells or reservoirs.

C. Production Rate and Head Loss Considerations

- Production (loading) rate is generally defined as the flow rate over the bed surface area: gpm/sf. Normally this ranges from 5 to 12 gpm/sf; however, higher loading rates are possible given sufficient study to verify proper performance.
- Head loss is generally not a controlling factor in operation of pressure filters. Instead, backwash is usually initiated based upon solids breakthrough, which means the full depth of the bed has been filled with accumulated solids. The designer must therefore

select filter feed pumps with ample head and capacity to fully utilize the solids storage capacity of the media.

- Manufacturers of filter equipment usually have good knowledge about the general capabilities of their equipment and have attempted to provide systems that are efficient. However every process stream is different, and the designer must conduct pilot tests to establish pretreatment needs and to know if the filter performance can be optimized at the full range of expected loading situations.

D. Backwashing

- Backwashing of pressure filters is usually initiated based upon solids breakthrough, which means the full depth of the bed has been filled with accumulated solids. However, it is recommended that each online filter unit undergo at least one backwash cycle per day in order to prevent mudball formation and to purge grease and biological growths.
- During the backwashing cycle, that filter unit is offline and the other online units must handle all of the plant flow.

E. Control Considerations

- Pressure filters are almost always a “packaged” system that has a pre-engineered control system. Such systems may have some optional operating modes, but generally lack potential for optimization and flexibility.
- Pressure filters typically utilize many motor-operated valves, instruments, and control devices to accomplish automatic operation of production and backwash cycles.

T4-2.4.3 Slow Sand Filters

A. General

Slow sand filters are a low-cost, noncomplex technology that has been used successfully for many years. This may be a particularly good system for small wastewater plants. A slow sand filter consists of a large flat sand bed that is intermittently flooded and drained. Multiple beds are needed to maintain constant processing. As filtrate is collected in an underdrain system, solids accumulate on the surface and must be physically removed. In most cases slow sand filters may be expected to produce effluent quality equivalent to gravity or pressure filters, and may operate efficiently without chemical filter aids for most secondary wastewater effluents. Color, algae, and turbidity removal will likely require preceding chemical coagulation.

Media depth is normally about 36 to 42 inches supported on about 10 to 12 inches of gravel.

B. Coordination With Plant Hydraulic Profile

- Feed water is usually pumped to the filter bed(s) although gravity feed is also suitable if sufficient hydraulic grade is available.

- Filtrate water should be able to flow by gravity to the next process stage.

C. Production Rate and Head Loss Considerations

- Design loading rates may range from 3 to 16 mgd per acre.
- High loading rates may be applied if the media is relatively coarse and/or solids loadings are low.
- Low loading rates are needed if the media is fine and/or solids loadings are high.
- Head loss buildup to maximum is predictable and very slow, ranging from a few days to many weeks.

D. Media Cleaning

- Cleaning of filter media is performed by scraping about 2 to 3 inches of the surface, thus exposing a relatively clean layer for the next operating cycle.
- The dirty sand may be cleaned and reused in the filter or it may be landfilled, incorporated with compost (or precompost), or other appropriate and environmentally sound method of reuse or disposal.
- The process of scraping off layers may continue until the effective media depth is 16 to 20 inches. The sand bed must then be refilled to the maximum media depth, leveled, and returned to service.

E. Control Considerations

- The filtered water outlet structure should be designed to maintain submergence of the media under all conditions so that air binding is prevented.
- The filter should be operated under submerged conditions of 4 to 5 feet of head, with the maximum head loss across the media not exceeding the submergence depth.
- Effluent flow from each filter bed should be controllable with a valve or adjustable weir.
- Special care should be taken to apply flow to the filter bed without disturbing the surface of the media. Gradual filling of the filter may be necessary until sufficient water depth is achieved to allow maximum water rates.
- Manual monitoring and controls are usually adequate.

T4-2.5 Other Types of Filtration

In addition to granular media filters, fine screens and synthetic media can be applied to wastewater for physical treatment by filtration. The application of these technologies has not been widespread; however, with careful application and design they can be used successfully.

T4-2.5.1 Fine Screens

Fine screens, or microscreens, for solids removal are not to be confused with fine screens for preliminary treatment in a headworks. While fine screen media is generally available in openings ranging from 6 micron up to 6 mm, fine screening for application in physical removal of solids in wastewater treatment typically ranges between 6 and 100 micron.

In general, fine screens are not capable of achieving the same effluent quality as granular media filters because they comprise a single, thin, synthetic or metallic layer in which to trap the solids. Thirty to 60 percent removal of solids by fine screens is not uncommon.

Fine screens for solids removal are generally drum screens with fine media attached to the drum. The media is normally a synthetic cloth-type media such as polypropylene, perforated stainless steel, wedgewire stainless steel, or stainless steel mat. The screens are usually internally fed with the filtrate passing through the drum to the outside. Backwash for the screens is normally pumped to a header to wash the media. The backwash is then collected in a trough for return to an upstream process.

Fine screens can often offer significantly higher loading rates (10 to 25 gpd/ft^2) than granular media. This can result in space savings over granular media filters.

Fine screens can be appropriate if the effluent requirements are somewhat less stringent than granular filters could easily achieve. In addition, fine screens may be appropriate if space constraints are a concern.

Design considerations for fine screens include the following:

- Hydraulic and solids loading rates. The designer is cautioned to evaluate loading rates in terms of net submerged media. In a rotating drum screen only a portion of the media is available for filtration at any given time. Media support structures also deplete effective filtration areas.
- Backwash requirements and efficiency of backwash method. Backwash should be positive, high-pressure sprays. Doctor blades may be adequate on pretreatment screens but are not recommended for solids removal applications. In addition, if grease is a concern, it may be necessary to wash or backwash the screen occasionally with hot water and/or chemicals.
- Head loss capability and requirements of the fine screen.
- Ease and frequency required for media replacement and repair.
- Tank and seal design to prevent contamination of treated water with untreated water.

T4-2.5.2 Synthetic Media

There are various manufacturers of synthetic media. Contact manufacturers for further information.

T4-2.6 Other Types of Physical Treatment

Recent developments in applying new technology to physical treatment of wastewater include the application of membrane technology and various forms of ballasted flocculation. Both of these technologies are relatively new, with minimal design criteria available. It is strongly recommended that a designer considering applying these technologies carefully investigate the technology and conduct pilot trial testing to verify feasibility, operational characteristics, design parameters, and sidestream characteristics. A brief discussion of these technologies follows.

T4-2.6.1 Membranes

Membranes for treatment of wastewater are available in a variety of pore sizes and material types. Membranes typically are available in the micron range (microfiltration), less than micron range (ultrafiltration), nano range (nanofiltration), and molecular range (reverse osmosis, or RO). Many times a combination of sizes may be necessary to achieve the effluent quality with the most economical process sizing. In other words, it may be necessary or more economical to use microfiltration ahead of RO to prevent fouling of the RO membrane or maximize the loading rate and thus minimize the size of the RO unit.

A. Applications for Membranes

- Tertiary treatment to achieve high quality effluent.
- High quality reuse applications.
- Ground water recharge.
- Expansion of treatment capacity on limited footprint sites.

B. Design Considerations When Evaluating the Use of Membranes

- Flux rate (hydraulic loading/area of media).
- Reject rate or recovery rate (i.e., how much water is rejected for each unit of water produced).
- Transmembrane operating pressure (i.e., the amount of pressure required to operate the membrane and the amount of pressure the membrane can handle).
- Fouling rate of the membranes.
- Backwashing capability or chemical clean-in-place (CIP) capability and the success of either.
- Overall operating costs including membrane replacement, power, chemicals for cleaning, and labor for membrane maintenance and replacement.

In addition to providing high quality effluent, membranes can offer potential for small footprints and reduced or even eliminated downstream disinfection.

T4-2.6.2 Ballasted Flocculation

Ballasted flocculation comprises the addition of particles (microsand) in a clarifier or flocculation basin ahead of a clarifier to enhance the settleability of the solids in a wastewater stream. The technology has been applied in water treatment on a limited but very successful basis, and is becoming increasingly popular. The main advantages of ballasted flocculation include significantly reduced footprints compared to conventional settling processes and the potential for reduced chemical dosages when chemicals are required for flocculation and coagulation.

A. Applications for Ballasted Flocculation

- CSO treatment.
- Primary treatment.
- Tertiary treatment.
- Phosphorus removal.
- Expansion of treatment capacity on limited footprint sites.

B. Design Considerations for Ballasted Flocculation

Design considerations are similar to those for conventional settling and tertiary clarification, including:

- **Loading rates**. Ballasted flocculation can achieve very high loading rates on a unit process basis. Rates of 10,000 to 40,000 gpd/sf have been reported.
- **Solids removal efficiency**. Removals of up to 80 percent or more on CSO and primary treatment applications have been reported.
- **Chemical requirements**. Ballasted flocculation requires the addition of a coagulant (alum, ferric chloride, ferrous sulfate, etc.) and coagulant aid (polymer) in addition to the particle introduced to enhance settling.

T4-2.7 Design Considerations

The design engineer should consider, evaluate, and provide justification for filter designs or specified package filter systems for the following factors.

T4-2.7.1 Number and Size of Filters

- Filters are normally sized for flow capacity based on media surface area (gpm/sf).
- The minimum required filter surface area should be based on the peak flow rate.
- Proprietary and pressure filters are normally sized by the manufacturer.
- The filter system should be comprised of multiple units so that at least one unit can be backwashed or removed from service without overloading the remaining units.
- Where flow cannot be interrupted, at least two filter units should be provided. For small systems where flow can be temporarily interrupted (such as lagoon systems or flow equalization tankage), a single filter unit may be satisfactory.

T4-2.7.2 Filter Type

- For large installations there are few alternatives for filter type; most are individual custom designs of the gravity, batch-backwashing type.
- For medium and small installations there may be several possible options because of the availability of small package systems (i.e., gravity, pressure, batch backwash, continuous backwash, slow sand, etc.).
- The design engineer should select a filter system (with appurtenances) appropriate for the skill level of the operator(s).
- The design engineer should select a filter system that is appropriate for the available site area and geotechnical foundation and ground water conditions.

T4-2.7.3 Bed Configuration Depth

- Depth and size of media should consider needed solids storage capacity (length of filter run) and head loss limitations.
- If chemical filter aids are used without a flocculation basin, some of the filter beds may need to be used for flocculation and would therefore be unavailable for solids storage.

T4-2.7.4 Media Characteristics

Selection of granular media shall be based on pilot testing of the particular water or researching comparable installations.

T4-2.7.5 Backwash System

- The filter system should be comprised of multiple units so that at least one unit can be backwashed without adverse effects on the remaining online units.
- The source of backwash water should be disinfected filtered water. This is normally drawn from the filtrate clearwell or a backwash storage tank.
- Adequate clearwell volume or backwash supply storage must be provided for consecutive backwashing of 50 percent of the filters.
- A standby washwater pump must be provided.
- Washwater flow meter(s) and control or throttling valves must be provided to obtain the proper rate of filter washwater flow.
- A means of observing the washwater flow should be provided.

T4-2.7.6 Appurtenances

Mechanical equipment for supporting the filter operations may include feed pumps, backwash pumps, air compressors, and automatic valves.

T4-2.7.7 Reliability

If pumped backwash is used, at least one standby washwater pump must be provided.

T4-2.7.8 Controls Systems and Instrumentation

There are three basic methods of filter operation: constant rate, constant pressure, and variable declining rate. It is sometimes advantageous to have the operational flexibility to use more than one method.

T4-2.7.9 Chemical Addition Systems

Almost all filtration systems require chemicals be added to the process stream to modify the water chemistry and/or solids and make the filter function efficiently. Coagulation and flocculation are the processes of blending or mixing chemicals into the process stream to cause a chemical reaction with the water and solids (colloidal or dissolved), thus creating a floc particle that can be efficiently captured by the filter media. The following are some general guidelines:

- Chemical coagulants must be applied to the process stream in the proper concentration, and in a manner that promotes thorough contact (flash mixing). Adding too much chemical will cause poor coagulation.
- Sometimes it is advantageous to adjust the water chemistry (pH, alkalinity, etc.) prior to application of coagulants. Adding lime is a common practice.
- Various chemical and physicochemical reactions may occur that are able to create floc particles or precipitates. The most important function of a chemical coagulant is to destabilize the surface electrical charge of the colloidal solid particles so that they will attract and form an agglomeration (floc).
- Floc particles must have the proper characteristics for effective filtration and backwashing to be accomplished. The floc characteristics must be compatible with the filter media and loading rates in order to optimize filter performance. Such characteristics of the floc include size, density, strength, electrical charge, stickiness, etc.
- The designer’s role in chemical selection and application is to know the desired characteristics for the floc as they relate to the specific process water and filter media and how the operator can manipulate the system to create those characteristics. The only way to provide a definitive design for a filter’s chemical application system is to conduct pilot tests on the actual process water using as many chemicals as practical, then make provisions within the full-scale system for some additional flexibility.
- Design features that provide flexibility for adjusting and optimizing the chemical application systems include the ability to apply multiple chemicals to the process stream (such as gaseous or liquid chlorine, liquid alum, emulsion polymer, lime slurry, etc.) together with many application and sampling points in the process stream.
- The hydraulic flow conduits must be designed to prevent turbulence, which would sheer floc as it is conveyed to the filter bed.
- All chemical systems should be designed with provisions for easily measuring the bulk quantity on hand by means of scales, level gauges, etc.

- All chemical systems should be designed with provisions for easily measuring instantaneous dosage or application rate by means of calibrated cylinders or low flow meters.
- All chemical systems should be designed with provisions for thorough mixing with the process stream at all points of application by means of diffusers, nozzles, mechanical mixers, hydraulic turbulence, etc.
- All chemical systems should be designed with sufficient bulk storage to accommodate economical purchase and shipping costs. Bulk chemical storage should be designed to prevent undesirable conditions (moisture, freezing temperatures, excessive heat, sunlight, etc.) which would accelerate deterioration of the chemical.
- Bulk chemical storage and feeding areas must be designed for safe and convenient handling of chemical containers.

T4-2.8 Recommended Design Features

- The filter shall be covered if necessary to prevent freezing, block sunlight (algae growth), promote safety, etc.
- Access shall be provided for operator inspections and servicing.
- Sufficient freeboard shall be provided on channels, flumes, and tanks to preclude flooding caused by overflows.
- Adequate drains should be provided on tanks, pipes, and channels to facilitate dewatering for servicing.
- Shutoff valves and piping or channels shall provide sufficient flexibility for operation/isolation of portions of the facility.
- The filtrate piping or channels shall provide for filter-to-waste or recirculation.
- Each filter unit shall have a head loss gauge device.
- Each filter unit shall have a means of measuring flow rate.
- Turbidimeter(s) should be installed as necessary to match control methods, or at a minimum, to ensure adequate effluent quality.
- Each filter unit shall have a means of manually initiating the backwash cycle.
- Piping and channels should be equipped with numerous (extra) fixtures for applying chemicals.

T4-2.9 Operational Considerations

Efficient operation of a filter system requires that the operator(s) understands the fundamental mechanisms that a particular filter system uses for removing solids from the water stream. The operator(s) should receive complete training from the manufacturer or engineer and have a detailed O&M manual written specifically for that facility. In addition:

- The filter system should be inspected daily to verify that all mechanical equipment is functioning properly, and to identify leaks or other items needing service or repair.
- Filter plant data should be recorded daily. Data may include volume of water treated, volume of backwash produced, filtrate turbidity, current chemical dose,

quantity of chemical used, quantity of chemical remaining in storage, run hours on auxiliary equipment, etc. The design engineer should develop an appropriate checklist.

- Periodically (monthly and annually), the operator should accumulate the filter plant's operational and cost data and prepare a summary of the filter performance in terms of cost-per-volume treated or cost-per-pound of solids removed. The operator should look for trends that may indicate inefficient, expensive, or inferior performance and investigate any problems.
- The filter plant should be given an annual (or other appropriate frequency) in-depth inspection and servicing. In particular, the media should be inspected for proper depth, mud balls, encrustations, or other physical degradation that would adversely affect performance. All deficiencies should be corrected to restore optimum performance.

T4-2.10 Reliability Criteria

All filtration unit processes shall be provided with at least one reliability feature, as follows:

- Alarm and multiple filter units capable of treating the entire flow with at least one unit not in operation.
- Alarm, short-term storage or disposal provisions, and standby replacement equipment.
- Alarm and long-term storage or disposal provisions.
- Automatically actuated long-term storage or disposal provisions.
- Alarm and standby filtration units.

T4-3 References

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